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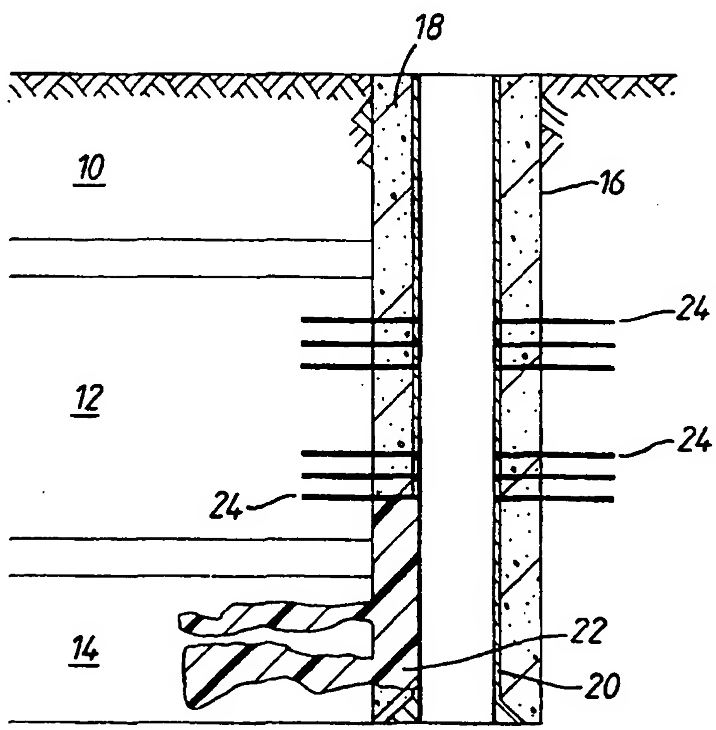
(54) Title: METHOD FOR ISOLATING A WELLBORE FORMATION ZONE

(57) Abstract

A method for zone (10, 12, 14) isolation or replacing a damaged or corroded casing (20) with a solidifiable epoxy resin mixture. An amount of the mixture sufficient to form a hardened plastic or solid, underwater or at low wellbore temperatures that is able to withstand downhole stresses, is placed into the wellbore (16) so as to bind with the undamaged casing (20) and close off any thief zone (22). Subsequently, the mixture forms a hardened solid. The hardened solid is milled out if necessary so as to form a resinous casing the size of the original casing (20).



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METHOD FOR ISOLATING A WELLBORE FORMATION ZONE

This invention is directed to a method for isloating a zone of a formation or reservoir penetrated by a wellbore. More particularyl, the invention related to a method for the repair or replacement of a damaged or corroded section of wellbore casing located in a subterranean formation.

During the course of well drilling operations, a wall of a wellbore being drilled is generally sealed and stabilized by means of a protective steel casing which is lowered through a wellbore. Afterwards, the casing is cemented in place after retrieval of the drilling assembly. Setting a steel casing in a well is a time consuming and expensive procedure. Since the wellbore is essential to removing desired fluids from a subterranean formation, it is necessary that the wellbore casing remains intact to make for a more efficient operation and avoid the loss of wellbore fluids into the formation.

Often during the production of hydrocarbonaceous fluids or other desired fluids from a formation via a wellbore, the wellbore becomes damaged or corroded. The damage may be caused by excessive pressure within the wellbore which will cause a section of wellbore casing to fail thereby interfering with its integrity. Also, wellbores which are located at levels below about 5,000 ft (1524 m) will often have an environment where high temperatures, high pressures, and corrosive chemicals are encountered. When these chemicals, pressures and temperatures combine, casing corrosion often occurs thereby necessitating the repair of a section of the casing so as to maintain its integrity thereby avoiding a loss of desired fluids into the formation.

Depending upon the composition of the casing which is used in the wellbore, the expense of replacing the wellbore's casing can vary. When stainless steel casings are used for example, replacement costs can be substantial. For these reasons, it is desirable to have a method for repairing the casing in the wellbore so as to maintain the efficiency of operations for

removing desired fluids from the formation while at the same time minimizing downtime and repair costs. Heretofore, it has been necessary to remove the entire wellbore casing and replace it with new casing. This of course is a time consuming and expensive operation.

Often the wellbore is filled with fluids, particulary brine, which interfere with the integrity of many gel systems utilized for zone isolation. During zone isolation, the integrity of a subsequently formed gel or blocking agent is compromised by enhanced oil recovery (EOR) operations which employ water or carbon dioxide. Carbon dioxide can cause a gel or blocking agent to deteriorate in an acid environment which shortenes its life and minimizes its effectiveness. Low temperatures encountered in some formations also keep some gels or blocking agents from making effective gels or blocking agents.

Therefore, what is needed is a simple and inexpensive method for zone isolation, and repair or replacement of a wellbore casing in situ so as to avoid loss of operational time, the production of desired fluids from the formation, or diversion of injection fluids to the oil-bearing formation when low temperatures or acidic conditions are encountered.

According to the present invention there is provided a method for isolating a zone of a formation or reservoir penetrated by a wellbore comprising:

a) directing a solidifiable epoxy resin mixture admixed with a curing agent into a desired zone of said formation via the wellbore which solidifiable mixture is in an amount sufficient to fill said zone to a desired depth in said formation;

b) allowing said resin and curing agent to remain in said zone for a time sufficient to form a hardened solid able to withstand environmental conditions existing in the zone while precluding fluid flow therethrough; and

c) removing any excess solid material from the wellbore

so as to form a solid wall bonded to and having a diameter substantially similar to said casing thereby isolating said zone from fluid flow.

In a particularly preferred embodiment the method is used for repairing a damaged or corroded wellbore section of casing located within said zone, in which case: in step (a) said solidifiable solid epoxy resin mixture is directed into the damaged or corroded section in an amount sufficient to fill a space or void within said damaged or corroded section; and the completion of step (c) results in the repair of the corroded or damaged section.

Advantageously, the solidifiable mixture comprises additionally a diluent and a filler.

Preferably, the solidifiable mixture is directed or flowed into the space or void and wellbore adjacent thereto by a positive displacement dump-bailer or by a coiled tubing.

Desirably, in step b) the solid which is formed has a fracture toughness able to withstand perforations being placed therein.

Preferably also, the hardened solid is able to preclude formation gases and liquids from flowing therethrough.

In step c) the solid wall desirably forms a liner with the undamaged or uncorroded casing.

When said zone is not located at the bottom of the wellbore, the solidifiable mixture can be directed into said zone by the placement of a mechanical packer below it.

It is preferred that the solidifiable mixture is hydrophobic and forms a hardened solid at a temperature of about 80° F (27°C) which solid is able to withstand temperatures encountered in steam-flooding EOR operation.

The solidifiable mixture desirably contains: a bisphenol-A epichlorohydrin epoxy resin with an epoxide equivalent weight of about 185 to about 192; or a bisphenol-F epichlorohydrin epoxy resin with an epoxide equivalent weight of about 166 to about 177.

In the preferred embodiment the solidifiable mixture contains: a bisphenol-A epichlorohydrin epoxy resin or a

bisphenol-F epichlorohydrin epoxy resin; a monofunctional glycidyl ether diluent comprised of C_8-C_{10} alkyl groups; and a phenalkamine epoxy curing agent, or a Mannich base aliphatic polyamine attached to a phenol curing agent. Preferably the mixture further comprises a filler.

If the wellbore is a water containing wellbore, then it is desirable that the mixture is unaffected by said water.

In one embodiment, after step (c), a steam-flooding, carbon dioxide flooding, water-flooding, miscible or immiscible EOR method is initiated in another zone of said formation.

Reference is now made to the accomapnying drawings, in which:

Figure 1 is a schematic representation of a cased wellbore where channels have been made in the casing thereby communicating the wellbore with a thief zone.

Figure 2 is a schematic representation which details the formation of a solid material in the wellbore and also in the area of the wellbore where the casing has been removed and underreamed. Additionally, it shows the solid material in a thief zone which communicated previously with the wellbore.

Figure 3 is a schematic representation which shows replacement of the damaged or corroded casing and cement behind the casing by the solid plastic after removing excess solid material from the wellbore.

As is shown in Figure 1, a wellbore penetrates formation 10, producing zone 12, and thief zone 14. The borehole contains cement 18 and casing 20. During the removal of hydrocarbonaceous or other desired fluids from the formation, conditions existing at the lower portion of the wellbore have caused casing 20 to be damaged by channels 22. These channels 22 allow fluids to move from the wellbore into a thief zone 14. Ordinarily, it would be necessary to remove the entire casing 20 and replace it with a new casing.

In the practice of this invention, as is shown in Figure 2, a portion of casing 20 that contains channels 22 which communicate with thief zone 14 has been removed. After removing the damaged casing containing channels 22, borehole 16 is

underreamed to a desired size at a location just below perforations 24 above channels 22. Thereafter, a solidifiable mixture is flowed into casing 20 whereupon it also penetrates via channels 22 into thief zone 14. The solidifiable mixture is allowed to remain in the wellbore and thief zone 14 so as to form a thick solid wall which is able to withstand environmental conditions encountered at a preferred depth in formation 10. After the solidifiable mixture has formed a solid, a drilling operation is conducted within the wellbore to remove excess solid material from the wellbore. The underreaming provides the desired thickness of the plastic casing to withstand the downhole stress.

Once the solid material is removed from the wellbore, the casing is comprised of the remaining solid material that abuts the metal casing which was already in the wellbore. Any solidifiable material which flowed into thief zone 14 remains therein as a solid. The completed wellbore casing containing the repaired section comprising the solid material is shown in Figure 3.

In those situations where it is desired to repair a damaged or corroded section of casing 20 at a level higher than the bottom of the wellbore as is shown in Figures 1, 2, and 3 a drillable mechanical packer (not shown) can be placed below the portion of the casing which it is desired to repair or replace. Once the drillable packer has been positioned as desired in the wellbore, the solidifiable mixture is flowed into the wellbore and is placed on the drillable packer whereupon it flows into channels which communicate with a thief zone or other zone of the formation. Subsequently, the solidifiable mixture will form a solid material which is subsequently drilled out along with the drillable packer. Once this has been done, the well can be produced as desired. The solidifiable material may comprise a resinous material.

This solidifiable material can be used to isolate zones of a formation to prevent gravity override and for profile control. Gravity override and profile control are discussed in US-A-4844163.

One method for placing the resinous material into the formation is by use of a positive displacement dump bailer. This is a mechanical device, symmetrical in shape, which is filled with a mixture of resinous material and an acid or alkaline curing agent. It is lowered into the wellbore by a cable. The bailer is positioned at the desired depth above the damaged casing or packer and when activated, releases a metal bar in the top of the device. The bar falls downward inside the device and impacts the top of the fluid creating a downward-moving shock wave which travels through the fluid column contained in the bailer. The shock wave causes a shearing of metal pins in the bottom of the bailer and a subsequent downward movement of the small piston. This small piston uncovers ports to allow a release of the resinous material. The bar continues to fall through the bailer as fluid is released through the ports. The weight of the metal bar effectively adds to the weight of the fluid column being dumped. As the bar falls to the bottom of the bailer, the cylindrical bailer is wiped clean of the resinous material containing an acid or alkaline curing agent.

Other types of positive displacement dump bailers, which operate in a similar manner, may also be used. It is possible to deliver the resinous viscous material with curing agent therein in an open gravity-feed dump bailer. This is a bailer which is open at the top and closed at the bottom. When activated, the bottom cover, which is held by metal pins, is sheared by an explosive or by other means so as to open the bottom. Opening the bottom allows the resinous viscous material with curing agent therein to flow by gravity from the bottom of the bailer and into the damaged casing area and thief zone 14.

A coiled tubing may also be used to place the viscous resinous material at the site from which the damaged casing has been removed. The coiled tubing consists of a one-inch or other small pipe which is wound on a spool at the surface of borehole 16. The viscous resinous material and curing agent therein are placed in the end of the tubing and held in place by wiper balls at the top and at the bottom of the resinous material. The

tubing is then uncoiled and lowered into the wellbore above the site where it is desired to replace the casing. Thereafter, the viscous resinous material with curing agent therein is pressured through the tubing and released into the wellbore where it flows into the thief zone via channels 22 and contacts casing 20. Here it forms a solid in the wellbore 16 and thief zone 14. As is shown in Figure 2, the resinous material enters thief zone 14 via channels 22. Because the resinous material with curing agent therein is fast acting, a solid is formed in the wellbore and thief zone 14. This material, of course, can be held in place by a drillable packer if required. The material is allowed to harden in thief zone 14 and the wellbore.

The preferred resin for use herein comprises an epoxy resin, a curing agent, a reactive diluent, and a filler. An example of epoxy resin is Shell's EPON-828R, a bisphenol-A epichlorohydrin epoxy resin with an epoxide equivalent weight of 185-192. Another epoxy resin is Shell's EPON DPL-862, a bisphenol-F epichlorohydrin epoxy resin with an epoxide equivalent weight of 166-177. The epoxy resin is blended with a reactive diluent and a filler. An example of the reactive diluent is Scherling Berlin's Diluent 7, a monofunctional glycidyl ether based on alkyl groups of C_8-C_{10}. The diluent is used to increase pot life or gel time of the epoxy resin and to increase load capacity for the filler. In some cases, a large amount of filler (up to 50% by weight relative to the epoxy resin) is added to the resin mixture. It serves to increase the specific gravity of the resin mixture for gravity dump-bailing applications and for application in deep wells. The filler is also used as a heat sink to allow more working time. An example of the filler is a fine powder of calcium carbonate or silica flour. A crosslinking or curing agent is then added to the resin mixture. This makes a fast-reacting gel which hardens in a short period of time.

For typical oil field applications such as injection profile control, remedial cementing, and casing repair, epoxy curing agents manufactured by Cardolite Inc. can be used. These curing agents are sold under the NC-540, NC-541, and NC-541 LV

tradememames and can be purchased from Cardolite Inc. which is located in Newark, New Jersey, U.S.A. These curing agents are phenalkamine compounds with a long hydrocarbon chain attached to a phenoxy group. This curing agent participates in the crosslinking mechanism and forms a hard resin. Phenalkamine curing agents display a a strongly hydrophobic behavior after mixing with an epoxy resin. Thus, they are suitable for downhole applications where the epoxy system may mix with the wellbore fluids, typically brine. Hydrophobic behavior of the epoxy system ensures that the epoxy system will form a hard solid even when some mixing with wellbore brine occurs.

In order to confirm the effectiveness of this system, laboratory tests were conducted. In these tests, Cardolite NC-phenalkamine curing agent was mixed with the aforementioned epoxy resins. After three days of curing at a temperature of about 80° F (27°C), the epoxy system formed a hard solid having a compressive strength of at least 7,000 psi (48 MPa). This test, which simulated an application for an underwater environment, confirmed that the epoxy system can cure to a hard solid when the wellbore is full of brine.

Samples of the hard solid sample above obtained from crosslinking the epoxy resin with the phenalkamine curing agent were tested for resistance to carbon dioxide and hydrochloric acid. One sample was placed in two autoclaves and tested at a temperature of 80°F and a pressure of about 1,700 psi (12 MPa) for three weeks. One autoclave contained a highly saturated carbon dioxide and brine environment. The other contained a 28 volume % solution of hydrochloric acid. When examined, the sample showed substantially no deterioration thereby demonstrating that the sample was chemically resistant to high pressure carbon dioxide and brine as well as being tolerant to a strong acid. Although other samples showed a dry weight loss of about 10% after exposure to the strong acid, the residual strength of the samples was at least about 6,000 psi (41 Mpa). The integrity of the samples were substantially preserved.

Where it is desired to obtain a slightly higher temperature, Schering Berlin's Euredur 3123, a polyamide epoxy

curing agent, can be blended with Cardolite curing agents to increaase potlife.

For underwater and low temperature applications, another curing agent, Schering Berlin's Euredur 3254, can be used. This curing agent contains a Mannich base aliphatic polyamine attached to a phenol group.

To promote faster curing, a catalytic tertiary amine can also be blended with the aforementioned curing agents. For high temperature applications, an anhydride such as Ashland Chemical Company's phthalic anhydride or a liquid anhydride of methyl tetrahydrophthalic anhydride can be used.

The concentration and volume of curing agent utilized must be customized according to the temperature of the well right before the dump-bailing operation. This allows the resin to have about twenty minutes of flow time and to gel in about 60 minutes. The amount of various batches of the resinous material to be utilized depends on the hole size to be filled. The resin plugs the bottom of thief zone 14 and binds with the undamaged portion of casing 20.

The resinous or solid plastic which forms should have a fracture toughness able to withstand perforations being placed therein so as to remove fluids from a producing zone. In addition to forming a solid liner, the resinous material or plastic should be able to preclude formation gases and liquids from flowing therethrough.

As mentioned above, in order to thin the epoxy resin thus increasing the pot life, a five to fifteen weight percent solution of a reactive diluent is utilized. Use of this concentration of diluent allows for efficient draining of the dump-bailer or for speeding up resin penetration into any cracks or channels behind the casing. It has also been determined that it is best to use a resin which is substantially fresh. Freshness can be determined by a measurement of the resinous material's viscosity. If the viscosity is over a recommended tolerance limit, it should be rejected. The preferred viscosity range is about 4,000 to 11,000 centipoise at 75°F (24°C). A simple, rugged capillary viscometer is available to measure the

viscosity obtained. This viscometer can be obtained from Baxter Scientific Products.

In addition to casing repair, the epoxy resin and crosslinking system above mentioned can be utilized in oil field workovers such as zone isolation or remedial cementing. When used in zone isolation or remedial cementing, a mechanical packer can be positioned in the wellbore so as to prevent solidifiable material from entering an undesired zone. Once the desired volume of solidifiable material has been placed into the zone or damaged area, placement of solidifiable material into that zone or area is terminated and the material is allowed to form a hardened solid. Excess hardened material can be removed from the wellbore by drilling to minimize damage to the productive zones. After removing excess hardened material from the wellbore, production can be commenced or an EOR can be initiated in a desired zone.

The viscosity of the solidifiable material is tailored so as to flow into the zone desired to be isolated or repaired. A desired viscosity can be determined from core samples taken from the fomation, existing data, or by use of a survey of the vertical portion of the formation near the wellbore to determine the rate and volume of fluids entering various zones of the formation.

The first of these methods is known as a "spinner survey". In this method, a tool containing a freely rotating impeller is placed in the wellbore. As steam passes the impeller, it rotates at a rate which depends on the velocity of the steam. The rotation of the impeller is translated into an electrical signal which is transmitted up the logging cable to the surface where it is recorded on a strip chart or other recording device.

Radioactive tracer surveys are also used in many situations. With this method methyl iodide (131) has been used to trace the vapor phase. Sodium iodide has been used to trace the liquid phase. Radioactive iodine is injected into the steam between the steam generator and the injection well. Injected tracer moves down the tubing with the steam until it reaches the formation, where the tracer is temporarily held on the face of

the formation for several minutes. A typical gamma ray log is then run immediately following the tracer injection. The recorded gamma ray intensity at any point in the well is then assumed to be proportional to the amount of steam injected at that point.

Vapor phase tracers have variously been described as alkyl halides (methyl iodide, methyl bromide, and ethyl bromide) or elemental iodine.

Where desired, a miscible or immiscible, a steam-flooding, CO_2-flooding, or water-flooding EOR process can be initiated in either producing zone 20 or thief zone 14 of the formation after zone isolation or remedial cementing of a zone or casing.

Miscible recovery operations are normally carried out by a displacement procedure in which the solvent is injected into the reservoir through an injection well to displace oil from the reservoir towards a production well from which the oil is produced. Because the solvent, typically a light hydrocarbon such as liquid petroleum gas (LPG) or a paraffin in the C_2 to C_6 range, may be quite expensive, it is often desirable to carry out the recovery by injecting a slug of the solvent, followed by a cheaper displacement liquid such as water. A flooding process can be carried out under conditions of immiscibility or near-immiscibility by utilizing a displacing fluid such as carbon dioxide and an additive such as ethane which increases the solubility of the displacing fluid in reservoir oil. The additive is injected in a slug with the displacing fluid preferably followed by a slug of water to improve sweep. Afterwards,the displacing fluid alone may be injected to extract residual additive and oil. A number of slugs of displacing fluid, either by itself or with the additive may be injected, with intervening slugs of water and finally, water injection may be made to termination. This process is disclosed in US-A-4617996.

Steam-flooding processes which can be used when employing the procedure described herein are detailed in US-A-4489783 and US-A-3918521. US-A-4756369 describes a use of carbon dioxide in the presence of steam in heavy oil reservoirs to enhance the

mobility of heavy oil therein.

Although the present invention has been described with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the scope of this invention as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the appended claims.

Claims:

1. A method for isolating a zone of a formation or reservoir penetrated by a wellbore comprising:

a) directing a solidifiable epoxy resin mixture admixed with a curing agent into a desired zone of said formation via the wellbore which solidifiable mixture is in an amount sufficient to fill said zone to a desired depth in said formation;

b) allowing said resin and curing agent to remain in said zone for a time sufficient to form a hardened solid able to withstand environmental conditions existing in the zone while precluding fluid flow therethrough; and

c) removing any excess solid material from the wellbore so as to form a solid wall bonded to and having a diameter substantially similar to said casing thereby isolating said zone from fluid flow.

2. A method according to claim 1, for repairing a damaged or corroded wellbore section of casing located within said zone, wherein: in step (a) said solidifiable solid epoxy resin mixture is directed into the damaged or corroded section in an amount sufficient to fill a space or void within said damaged or corroded section; and the completion of step (c) results in the repair of the corroded or damaged section.

3. A method according to claim 1, wherein the solidifiable mixture comprises additionally a diluent and a filler.

4. A method according to claim 1 wherein the solidifiable mixture is directed or flowed into the space or void and wellbore adjacent thereto by a positive displacement dump-bailer or by a coiled tubing.

5. A method according to claim 1, wherein in step b) the solid which is formed has a fracture toughness able to withstand

perforations being placed therein.

6. A method according to claim 1, wherein the hardened solid is able to preclude formation gases and liquids from flowing therethrough.

7. A method according to claim 1, wherein in step c) the solid wall forms a liner with the undamaged or uncorroded casing.

8. A method according to claim 1, wherein, when said zone is not located at the bottom of the wellbore, the solidifiable mixture is directed into said zone by the placement of a mechanical packer below it.

9. A method according to claim 1, wherein the solidifiable mixture is hydrophobic and forms a hardened solid at a temperature of about 80° F (27°C) which solid is able to withstand temperatures encountered in steam-flooding enhanced oil recovery operation.

10. A method according to claim 1, wherein the solidifiable mixture contains: a bisphenol-A epichlorohydrin epoxy resin with an epoxide equivalent weight of about 185 to about 192; or a bisphenol-F epichlorohydrin epoxy resin with an epoxide equivalent weight of about 166 to about 177.

11. A method according to claim 1, wherein the solidifiable mixture contains: a bisphenol-A epichlorohydrin epoxy resin or a bisphenol-F epichlorohydrin epoxy resin; a monofunctional glycidyl ether diluent comprised of C_8-C_{10} alkyl groups; and a phenalkamine epoxy curing agent, or a Mannich base aliphatic polyamine attached to a phenol curing agent.

12. A method according to claim 11, wherein the solidifiable mixture further comprises a filler.

13. A method according to claim 11, wherein the wellbore is a

water containing wellbore, and the mixture is unaffected by said water.

14. A method according to claim 13, wherein after step (c) a steam-flooding, carbon dioxide flooding, water-flooding, miscible or immiscible enhanced oil recovery method is initiated in another zone of said formation.

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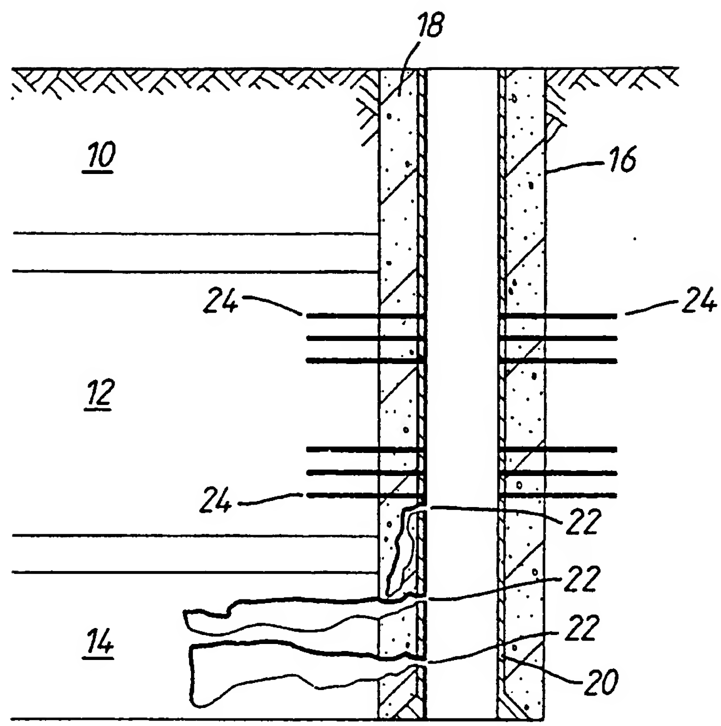

Fig.1

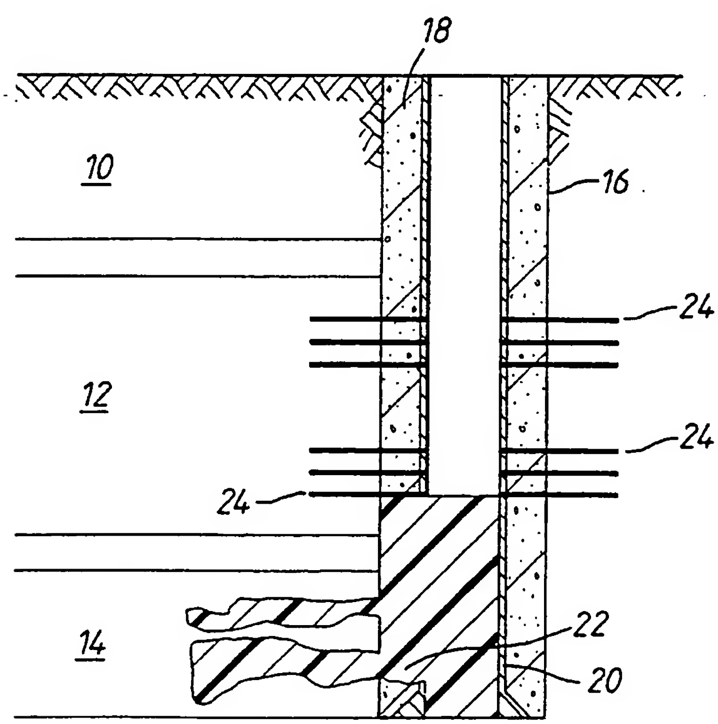

Fig.2

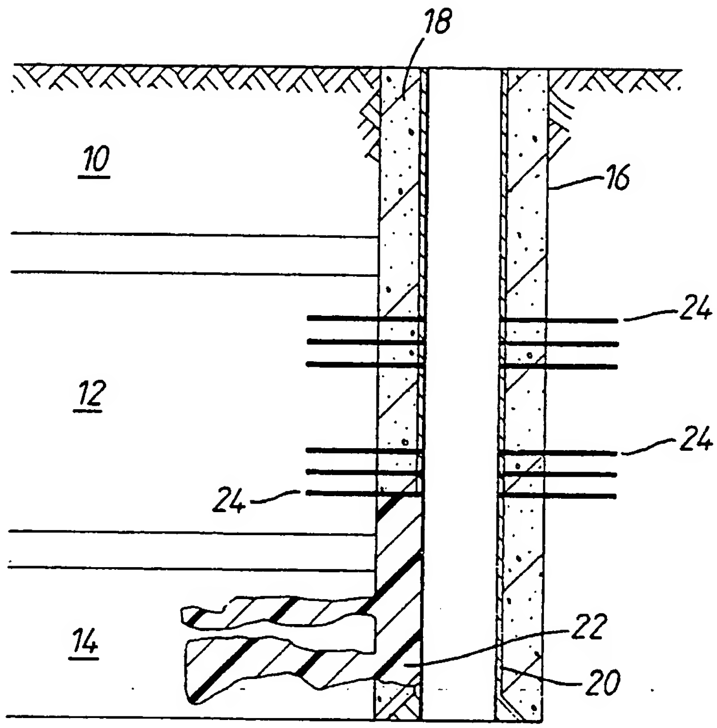

Fig.3

INTERNATIONAL SEARCH REPORT

Int[illegible]tional application No.
PC[illegible]94/03273

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :E21B 33/138, 33/14, 43/24, 43/22, 41/02
US CL : 166/277, 295, 272
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 166/277, 295, 272, 242, 268, 285, 387

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US, A, 5,129,458 (King et al), 14 July 1992, col. 1, lines 43-55 and col. 2, lines 61-67	1, 3-6, 8 ------------- 9-14
Y	US,A 3,121,463 (PERRY) 18 FEBRUARY 1964 (Figures 8, 9 and col. 9, lines 50-60)	9-14
A	US,A 3,111,991 (O'NEAL) 26 NOVEMBER 1963 (Figures 1,2, col. 1, line 70 to col. 2, line 5)	1,3,5,6,7,9-14
A	US,A 2,187,275 (MCLENNAN) 16 JANUARY 1940, (Figures 1,2, page 2, line 37 to page 3, line 21)	2,7
A	US,A 4,756,369 (JENNINGS, JR., ET AL) 12 JULY 1988 (Col. 1, lines 36-53)	4

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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03 MAY 1994	19 MAY 1994

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A 4,189,002 (MARTIN) 19 FEBRUARY 1980 (Col. 2, line 61 and col. 5, lines 33-42)	9-14